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The estimation of corneal rigidity by means of comparative tonometry

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Abstract

The estimation of corneal rigidity by means of comparative tonometry

Degree Type

Thesis

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Master of Science in Vision Science

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Lynn J. Coon

Subject Categories

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The Estimation of Corneal Rigidity by Means of Comparative Tonometry

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Faculty Advisor: Dr. Lynn J. Coon, O.D.

Submitted in partial fulfillment of the requirements for the degree of Doctor of Optometry at Pacific University College of Optometry.

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Grade

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SUBJECT RELEASE FORM

I. Basic Information

Project Title: The Estimation of Corneal Rigidity by Means of Comparative Tonometry

Investigators: Timothy G. Moore and Barry A. Eichenbaum

Advisor: Lynn J. Coon, O.D.

Location: Pacific University College of Optometry, Forest Grove, Oregon and Portland Optometric Clinic, Portland, Oregon.

Date: Fall 1978

II. Description of Project

The intent of this project is to attempt to estimate corneal rigidity using a number of subjects. This will be done by comparing the readings obtained by two forms of tonometry (a reading commonly taken to aid in determining the presence of glaucoma). Measurements will be taken by two standard forms of tonometry, the Schiotz Method and the Non-contact or air-puff Method. The Schiotz Method does involve actually touching the cornea and a local anesthetic in the form of eye drops will be administered to avoid any subject discomfort. The cornea will be examined before and after the tonometry.

III. Description of Risks

Risks are very minimal. Some subjects do report some irritation following tonometry. Some slight corneal abrasion may occur but is not likely. Subjects will be thoroughly checked before they are dismissed.

IV. Description of Benefits

Subjects will have a more precise knowledge of their intraocular pressure and be informed as to the status of their cornea's health. Corneal rigidity may be important in contact lens fitting for the purpose of myopia (near-sightedness) reduction.

V. Offer to Answer Any Inquiries

The experimenters will be more than happy to answer any questions you may have during the course of the project.

VI. Time Required

The subject can plan on donating no more than thirty minutes of their time to this project. This will be done in one visit.

VII. Freedom to Withdraw

You are free to withdraw your consent and discontinue your participation in this project at any time without prejudice to you.

I have read and understand the above.
I am 18 years of age or older.

Signed____________________________________ date__________

Review of the Literature

Tonometry is defined as "the measurement of ocular tension with a tonometer" (Schapero et.al. 1968), which still leaves one in doubt as to just what tonometry is, unless of course we define ocular tension. Ocular tension is in turn defined as "the resistance of the tunics of the eye to indentation, which depends upon the intraocular pressure, the thickness and rigidity of the tunics, the surface area, etc.,......" (Schapero et.al. 1968). Ideally one would wish to be able to directly measure the pressure within the eye by a means which would eliminate intervening factors such as rigidity of the tunics. Cannulation of the eye so that the internal pressure within the eye is directly measured by a mercury manometer (Kaufman 1972) would avoid the problems of mechanical indirect measurements which are influenced by technical difficulties as well as resistance to mechanical deformation or indentation by the elasticity of the tunics of the eye. Although it is perhaps the best theoretical means of determining intraocular pressure, cannulation presents many problems of its own. Anesthetics necessary for cannulation would most likely be a general anesthetic, usually barbiturates. Barbiturates have been found to lower the intraocular pressure (Moses 1975). Leakage of the aqueous and trauma to the eye are also factors which rule out cannulation as a practical means of determining ocular tension. Alternatively we are left with several methods of indirectly determining intraocular pressure by mechanical devices.

Two major approaches for the determination of ocular tension are currently in use: indentation tonometry and applanation tonometry, each with their inherent drawbacks and advantages. Indentation or Schiotz tonometry was for many years considered to be the standard method of determining intraocular pressure. More recently with the development of the Goldmann applanation tonometer, which is generally considered more accurate and more reliable, (Bengtsson 1972B, Moses 1958, Smith 1964, Kaufman 1972) has replaced the Schiotz indentation method as the standard.

The Schiotz tonometer is subject to a great degree of variability even when used by skilled persons (Glaster 1965). Applanation tonometry has been found to be subject to less variability than Schiotz tonometry (Bengtsson 1972B). Scott(1971) using several tonometers (Goldmann, Mackay-Marg, Maklakov and Schiotz) found the highest correlation between Schiotz and Goldmann tonometric findings. Population means for Goldmann applanation tonometry and Schiotz indentation tonometry have been found to have a high correlation although individual findings do not have such a high correlation (Armaly 1960).

Disparity between applanation and indentation tonometry has been to a large extent attributed to ocular rigidity (Buxton 1971, Moses 1958). Much of this disparity is attributed to the errors inherent in indentation tonometry. Factors which have been found to influence ocular rigidity are as follows: (from Buxton 1971)

A. Decreased ocular rigidity

1. Water provacative test
2. Endocrine exophthalmos
3. Myopia
4. Strong miotics in glaucoma therapy
5. Buphthalmic eyes
6. Megalocornea
7. Intraocular surgery
8. Hydration of the cornea

B. Increased ocular rigidity

1. Small cornea
2. Increased corneal thickness
3. Contraction of extraocular muscles

C. Questionable effects on ocular rigidity

1. Increased age
2. Escape of intraocular fluid by instrumentation

Factors which affect intraocular pressure more so than ocular rigidity would tend to have the same effect on indentation and applanation tonometry so that they would have minimal effects in the determination of ocular rigidity. These factors include blood pressure, sex, season of the year and time of day, all of which were considered to have independent effects on intraocular pressure (Bengtsson 1972A).

Applanation tonometry, more specifically the Goldmann method, is considered to be devoid of the influences of ocular rigidity and is thereby considered to be a more direct measure of actual intraocular pressure (Borish 1975). When a surface of three to four millimeters is applanated the surface tension due to tears and acting in a direction opposite to the force of resistance due to ocular rigidity equals and cancels the force of ocular rigidity (Moses 1975).

The following formula is used as a basis for applanation tonometry; the Imbert-Fick Law:

$$P=F/A,$$

where P=pressure, F force to applanate an area, A. A modification of this formula,

$$P=\frac{F+M-N}{A}$$

includes correction for force due to tear surface tension, M, and the force of resistance to corneal deformation, N (Moses 1975).

Formulations involving Schiotz tonometry are based primarily on the experimental data and work of Friedenwald (1937, 1954, 1957). From Borish (1975) Friedenwald's Formula for Schiotz tonometry is as follows:

$$a + bS=\frac{W \text{ (weight of the total plunger - indenting force)}}{P_t \text{ (the IOP with the tonometer on the eye)}},$$

where a and b are experimentally determined constants and S is the Schiotz scale reading. Clinically such a formulation is impractical and a nomogram devised by Friedenwald on a semilog plot is used for determination of intraocular pressure as well as an ocular rigidity coefficient (Borish 1975).

The difference between tonometric findings using the Schiotz tonometer and the Goldmann tonometer have generally been attributed to ocular rigidity as stated previously, since ocular rigidity is considered to have no effect on applanation tonometry. Regression analysis of data for Schiotz and Goldmann tonometry indicate a deviation from each other above and below the means and have been referred to as a regression effect (Levene 1971). Bengtsson (1973) suggests that regression curves deviating from Friedenwald's 1955 calibration curve are a consequence of many kinds of disagreement between the two methods of measurement.

Use of a differential in determination of ocular rigidity is not without precedent. Several values taken with the Schiotz tonometer using different calibration weights have been used on Friedenwald's nomogram in determination of a coefficient of ocular rigidity. Syrdalen (1970) used a Goldmann-Schiotz differential in formulating a means for determination of an ocular rigidity coefficient as follows:

$$K = \frac{\log P_t - \log(\text{appl. ton.} + 1)}{V_c - 0.44\text{mm}^3},$$

where K= the rigidity coefficient, P_t = intraocular pressure during tonometry (Friedenwald's table 1955), V_c = volume of corneal indentation caused by Schiotz tonometry (Friedenwald 1955), 0.44mm^3 = corneal indentation caused by applanation tonometry (Goldmann and Schmidt 1957). The addition of 1mm to the applanation tonometry values is to compensate for the increase in intraocular pressure from sitting to reclining as also found by Scott (1971).

The advent of modern technology has not passed up the area of tonometry. Many new and sophisticated electronic devices for measurement of intraocular pressure have appeared on the market in the past few years. Some of these new devices are no more reliable than previous instrumentation, specifically the Goldmann tonometer, which remains the standard by which the others are compared and calibrated. One of the most elaborate of these new devices is the

American Optical Non-Contact Tonometer. The A.O. Non-Contact tonometer is an applanation tonometer which applanates the cornea by means of compressed air. Many factors which may affect the reliability of readings with the Goldmann tonometer are circumvented by use of the A.O. Non-Contact tonometer. Factors introducing errors into Goldmann tonometric measurements are; surface tension of the anesthetic, improperly cleaned prism, improperly adjusted height, prolonged contact with the cornea, corneal edema, improper light placement, width of the fluorescein meniscus (Moses 1958). When properly calibrated and used as prescribed, the A.O. Non-Contact tonometer is not limited by any of these factors. Tests for reliability and effect on corneal integrity (Forbes et. al. 1974) show a correlation coefficent of +0.9 for the A.O. Non-Contact tonometer compared to the Goldmann tonometer. In this same study, repeated readings with the A.O. NCT showed no insult to the corneal epithelium.

The advantages and ease of use over Goldmann applanation tonometry are major factors in selection of the A.O. Non-Contact tonometer for this study. Applanation by means of the A.O. NCT will be compared with differential Schiotz readings in an attempt to ascertain a relationship between the differential of comparative tonometry and an ocular rigidity coefficient.

Methodology

Subjects for this study are to be selected from the general population. The only restriction upon selection of subjects will be that the subject's corneas have never been subject to any trauma which resulted in permanent corneal defects which are visible upon examination with the biomicroscope.

Prior to testing, each subject will be required to sign a release form describing the experiment and possible risks which may be involved.

Subjects will be examined with a biomicroscope before any tonometric measurements are taken to determine the state of corneal integrity. Pre-tonometric examination with the biomicroscope will also help to provide a basis for comparison of the corneal integrity with a second post-tonometric biomicroscopic examination to ascertain the extent of corneal damage due to tonometric procedures. The second biomicroscopic exam will be performed with sodium fluoroscein to highlight any epithelial damage.

The actual experimental procedure will involve taking standard tonometric readings with the American Optical Non-Contact applanation tonometer and readings with the Schiotz indentation tonometer. Measurements of intraocular pressure will be made first with the Non-Contact tonometer to avoid any possible "massaging" effects due to volumetric displacement which occurs with Schiotz tonometry. A minimum of three "valid" measurements of intraocular pressure will be made of each eye with the non-contact tonometer with an average of the three taken as the intraocular pressure.

Tonometric measurements will be taken with the Schiotz tonometer after administration of the appropriate local corneal anesthetic. Measurements will be taken in the standard fashion with the subject reclining. Three measurements will be made upon each eye. The three measurements will be made with three different calibration weights so that a differential comparison may be made as in determination of the Friedenwald coefficient of ocular rigidity. Comparisons will then be made between the differential Schiotz measurements and those obtained with the American Optical Non-Contact tonometer. Appropriate methods of statistical analysis will be employed.

Results and Discussion

The premise of the method of comparative tonometry is based on the idea that tonometric measurements of a subject taken by two different methods should differ from the mean of a population by the same amount if the two methods of measurement were linearly related. If this were the case, one would expect that a ratio of the difference from the mean divided by the mean would be equal in the two methods, i.e.,

$$\frac{\bar{X}_{NCT} - \text{NCT Reading}_n}{\bar{X}_{NCT}} = \frac{\bar{X}_{Schiotz} - \text{Schiotz Reading}_n}{\bar{X}_{Schiotz}} .$$

The ratios were assigned a negative value if the subject's reading was below the population mean and a positive value if the reading was above population mean. Differences between the ratios obtained from the NCT and those obtained from the Schiotz were taken as a measure of non-linearity between the two methods of tonometry.

It was our contention that these differences in values were related to corneal rigidity. The term, "corneal rigidity", is used somewhat loosely since comparisons were made using Friedenwald's Coefficient of Ocular Rigidity. To our knowledge, no comparisons have been made between readings taken at points on non-corneal surfaces and corneal surfaces. Technically, in this study we can not distinguish between ocular and corneal rigidity although the primary mechanical resistance to deformation is at the cornea when Schiotz tonometry is used. Hydrostatic resistance is presumed here to remain constant. The mechanical resistance of the cornea to greater or lesser degrees of deformation, dependent upon the Schiotz tonometer plunger load, is taken to be due to corneal rigidity.

A coefficient of ocular rigidity was determined for each subject by graphical projection on Friedenwald's nomogram (taken from Adler, 1975). The coefficient was obtained by using an average of three Non-contact tonometer readings and three Schiotz readings, each using a different plunger load. These values may be found in Table I.

In determining a measure of rigidity from comparative tonometry, the ratios obtained as previously described, may be both positive, both negative or one positive and the other negative. What was of primary concern was the difference between the NCT ratio and the Schiotz ratio,

$$\frac{\overline{X}_{NCT} - NCT_n}{\overline{X}_{NCT}} - \frac{\overline{X}_{Schiotz} - Schiotz_n}{\overline{X}_{Schiotz}} .$$

The difference between the two ratios was taken as a measure of corneal rigidity. This may be better visualized in diagrams I, II, and III. The higher the rigidity the higher the positive value. Values giving no difference can not be construed to have no rigidity but are points where there is a linear relationship between NCT and Schiotz tonometry. Values above this 1:1 relationship have a higher rigidity and those below it are of a lower rigidity. It is this non-linearity between the two different methods of tonometry that forms the basis for the quantification of corneal rigidity in this study.

The determination of corneal rigidity is based on population means for Non-contact and Schiotz tonometry done in this study. (See figures IV, V, VI, VII, and VIII.) The sample size of this study was somewhat small, but was adequate for statistical analysis. The Pearson product-moment correlation coefficient was used to compare figures obtained with comparative tonometry with those obtained from Friedenwald's nomogram, which is shown as figure IX. Correlation between the Ocular Rigidity Coefficient obtained from the Friedenwald nomogram and the NCT - 5.5gr. Schiotz values was only .42. Correlations with the NCT - 7.5gr. and NCT - 10gr. pairs to the Friedenwald coefficents were somewhat higher; .52 and .69 respectively. These last two comparisons show a fairly high positive correlation with the values of the Friedenwald nomogram.

Summary

It would be injudicious at this time to state that the method of assessing corneal rigidity as described in this study is valid beyond any doubt. Several aspects of the study limit the reliability of this method as an indicator of corneal rigidity. First of all, it is dependent upon population means, which in this case are based on a rather small population. Frequency distributions are illustrated superimposed on theoretical normal distributions in figures IV, V, VI, and VII. A comparison of theoretical normal distributions for the NCT, 5.5gr., 7.5gr. and 10.0gr. Schiotz findings of the population used in this study are illustrated in figure VIII. Here, it may be seen that there is a considerable difference in the distribution of the 5.5gr. Schiotz readings. This may or may not have had an effect on the correlation coefficient between the NCT - 5.5gr. Schiotz comparative rigidity measure and the Friedenwald Ocular Rigidity Coefficient. A study in which a larger population is used will probably provide more conclusive information.

The usefulness of an ocular rigidity coefficient has been considered to be of dubious value in clinical practice. (Adler, 1975). An ancillary aspect of this study may add credence to that statement. In an attempt to relate corneal (ocular) rigidity and Orthokeratology, a comparison between rigidity and acuity improvement was made with several patients involved in the Orthokeratology study being conducted at Pacific University College of Optometry. Correlation between the increase in decimal acuity and Friedenwald's coefficient of ocular rigidity was very low, .08 to be exact.

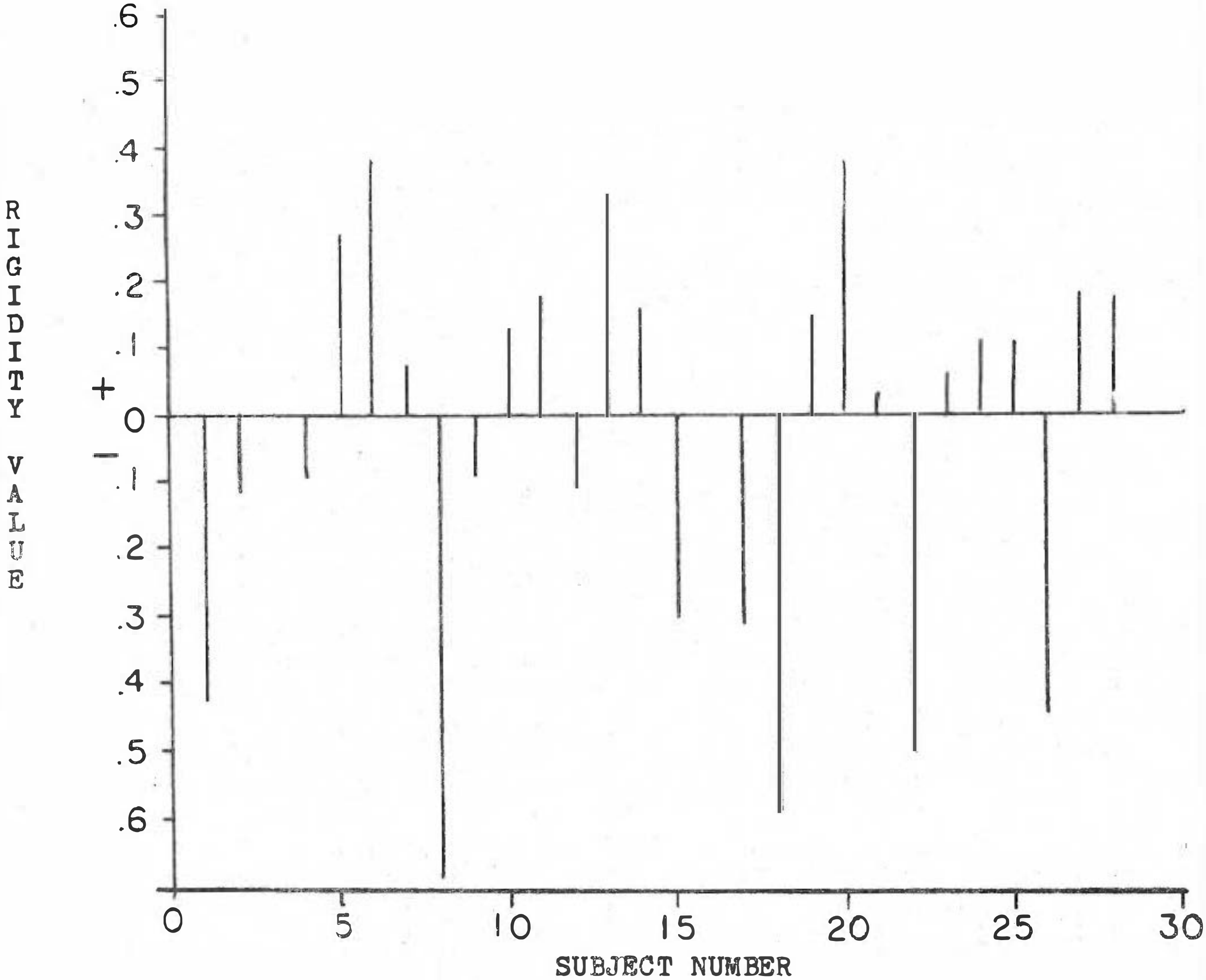
This study could provide the basis for a more comprehensive study in which the reliability of the comparative method may be more conclusively determined.

TABLE I

Friedenwald's Ocular Rigidity Coefficient as Determined by Graphical Plot of Schiotz and NCT Readings

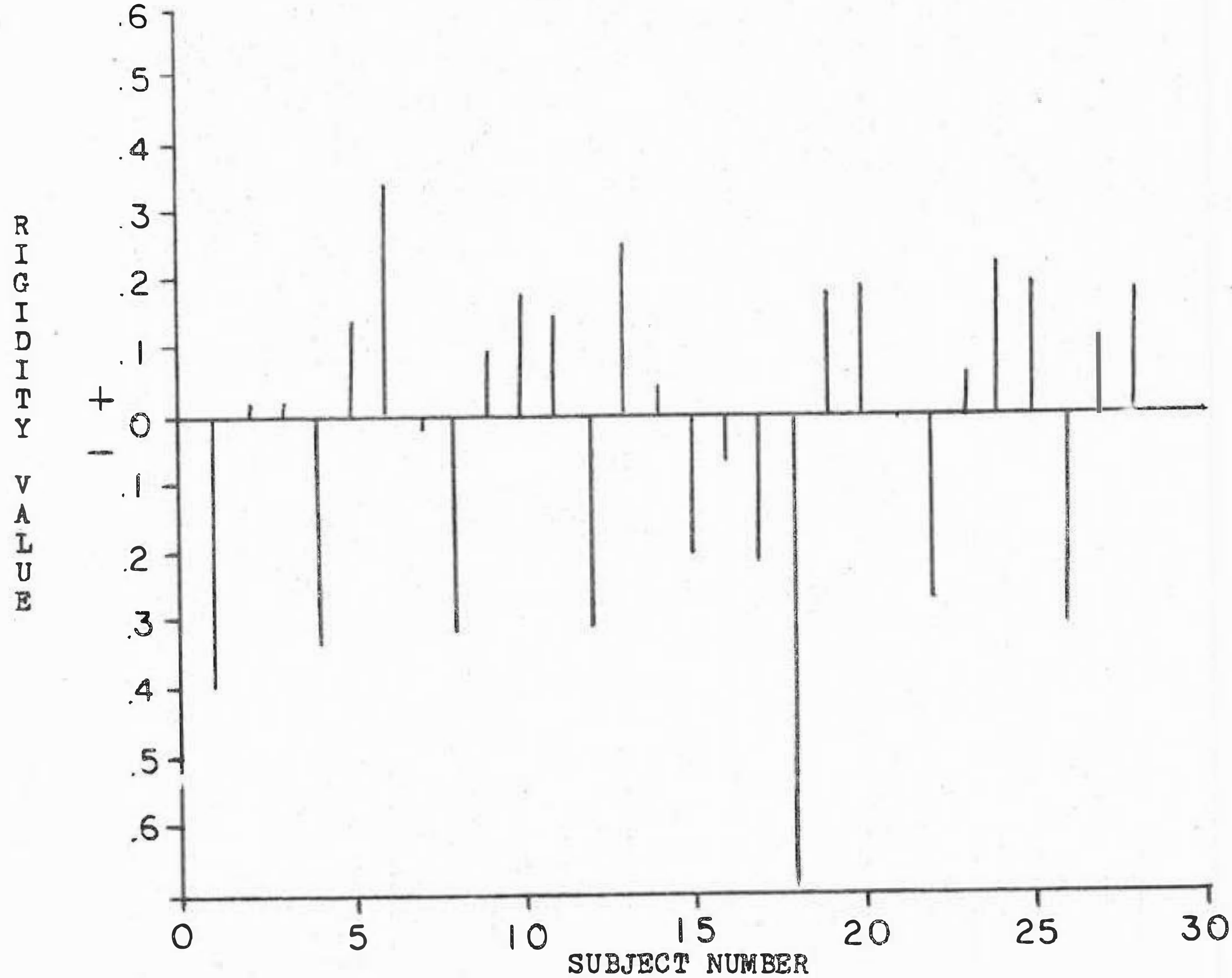
Subject No.	Friedenwald's Ocular Rigidity Coefficient
1	.016
2	.019
3	.021
4	.017
5	.019
6	.024
7	.019
8	.018
9	.020
10	.022
11	.026
12	.020
13	.0225
14	.022
15	.0175
16	.018
17	.021
18	.0175
19	.0195
20	.021
21	.020
22	.023
23	.0195
24	.0205
25	.0305
26	.0175
27	.0205
28	.022

FIGURE I



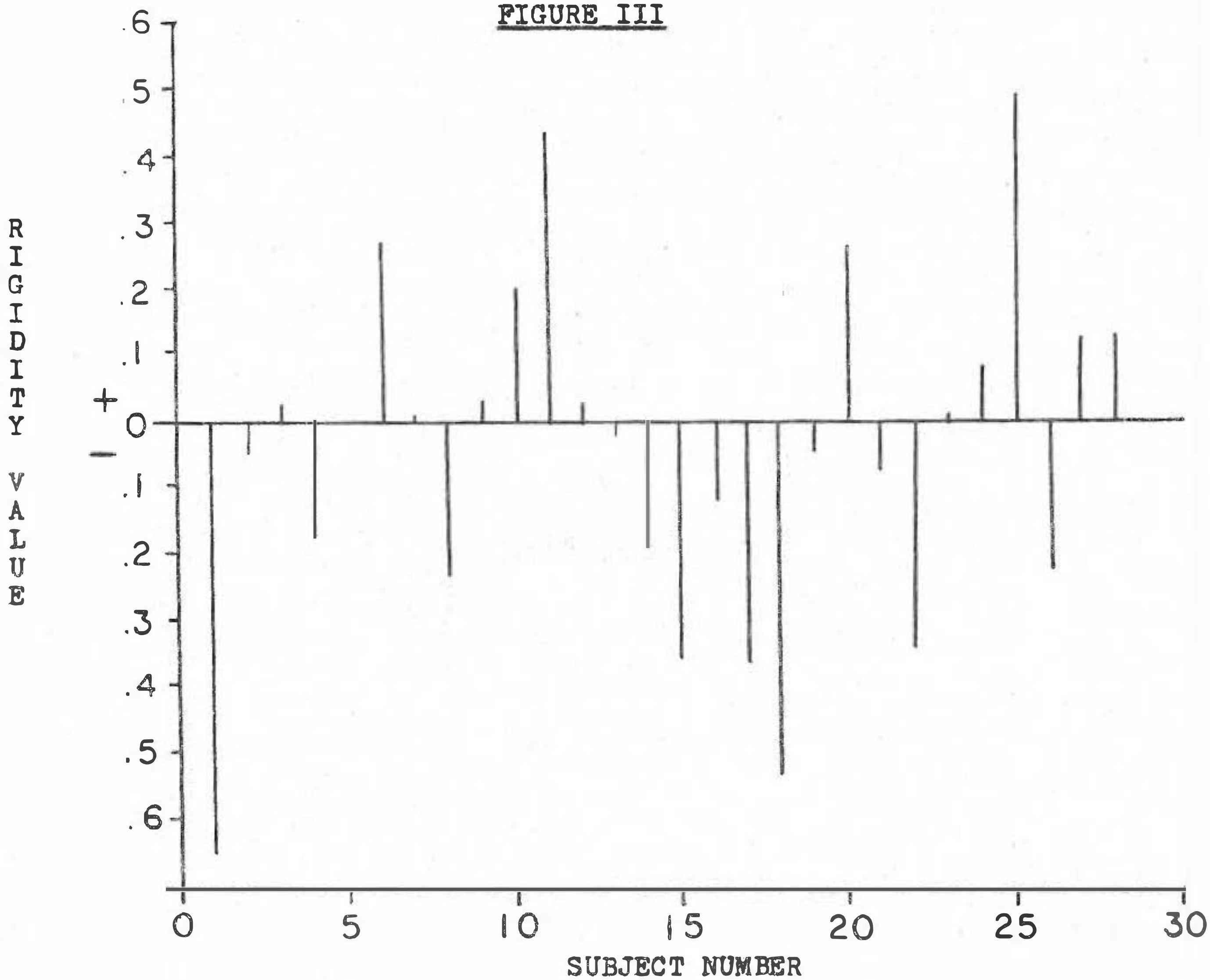
Rigidity values obtained by comparative method, using the Non-contact and 5.5gr. Schiotz tonometers.

FIGURE II



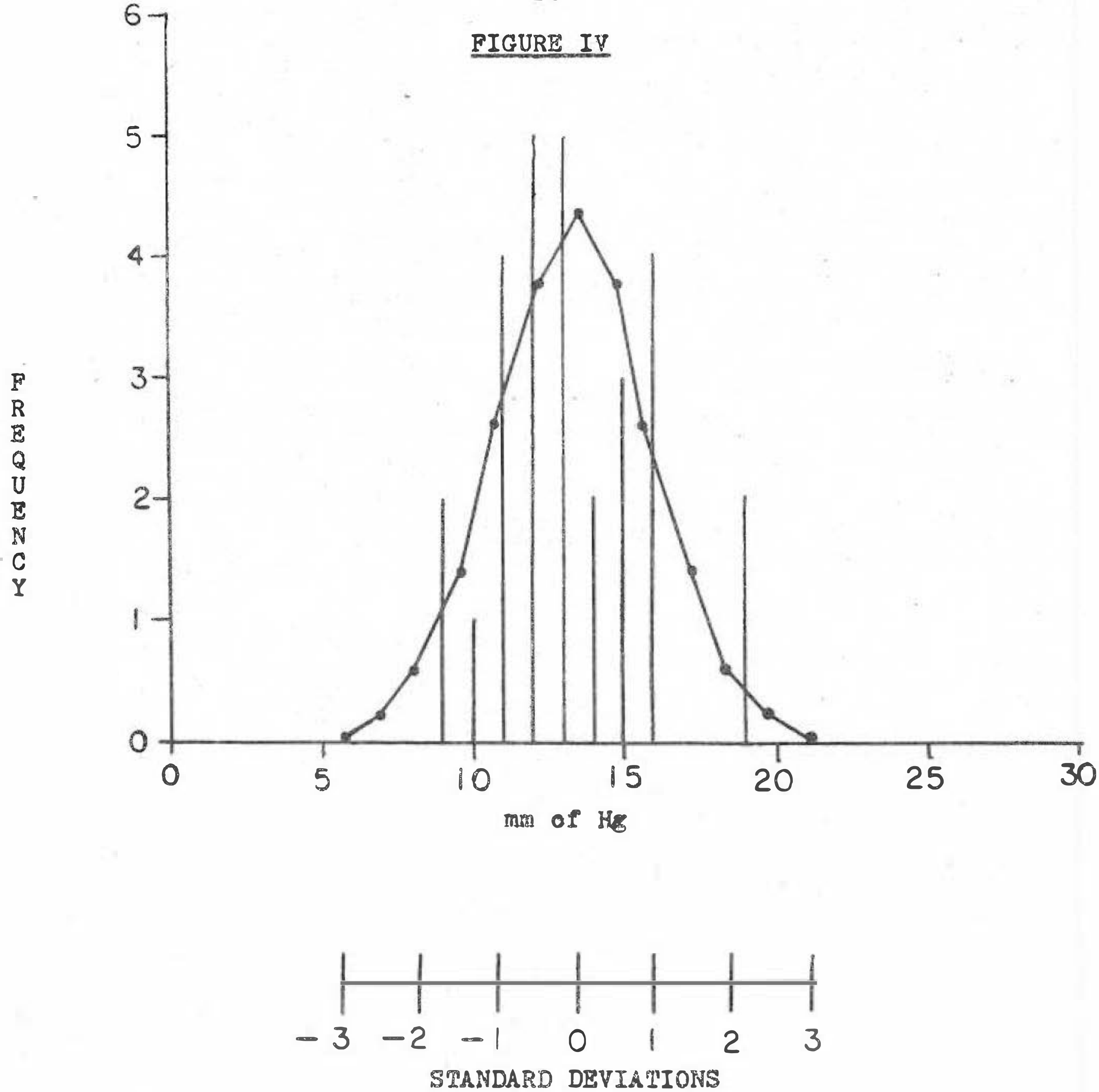
Rigidity values obtained by comparative method, using the Non-contact and 7.5gr. Schiotz tonometers.

FIGURE III



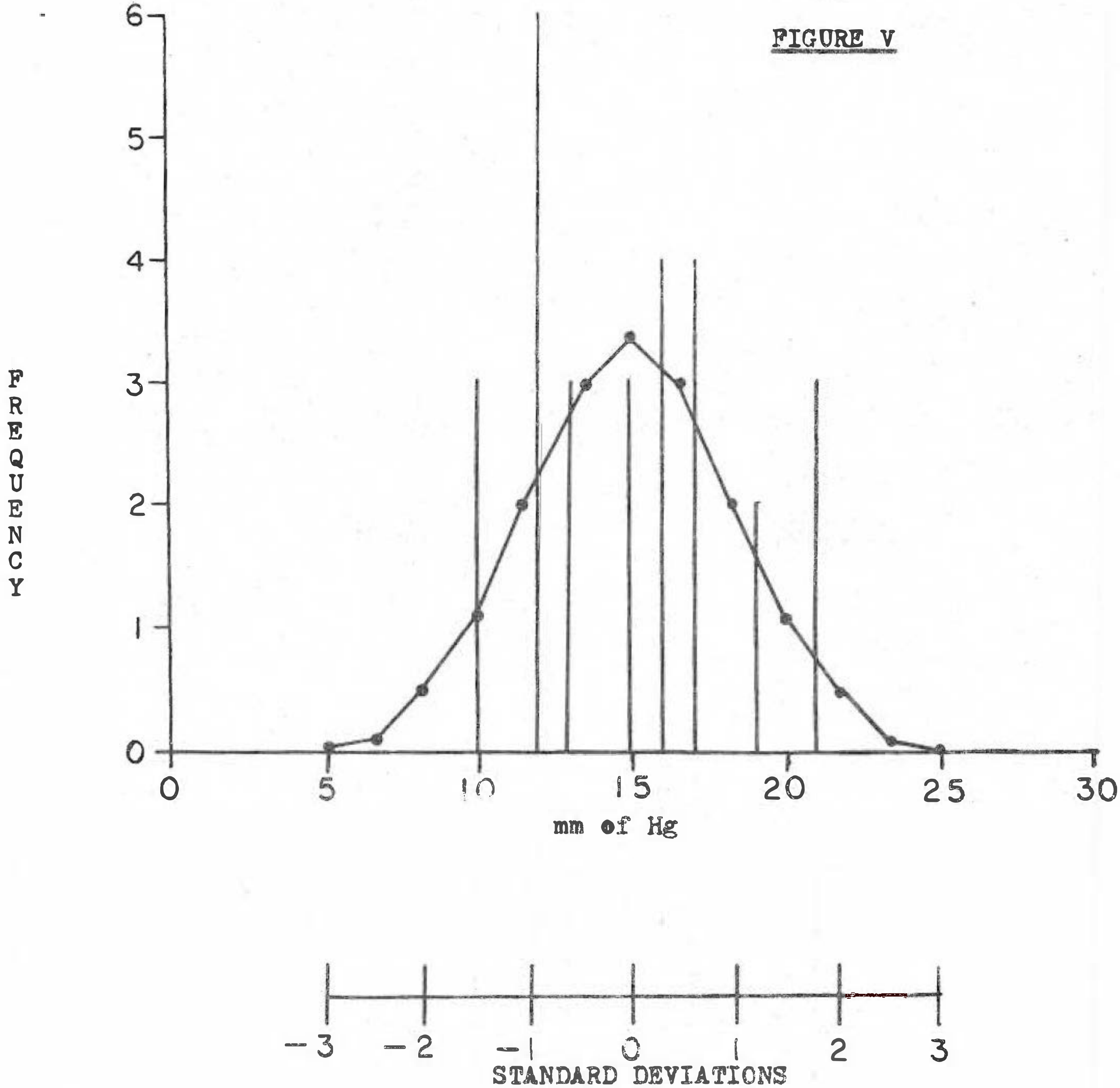
Rigidity values obtained by comparative method, using the Non-contact and 10.0gr. Schiotz tonometers.

FIGURE IV



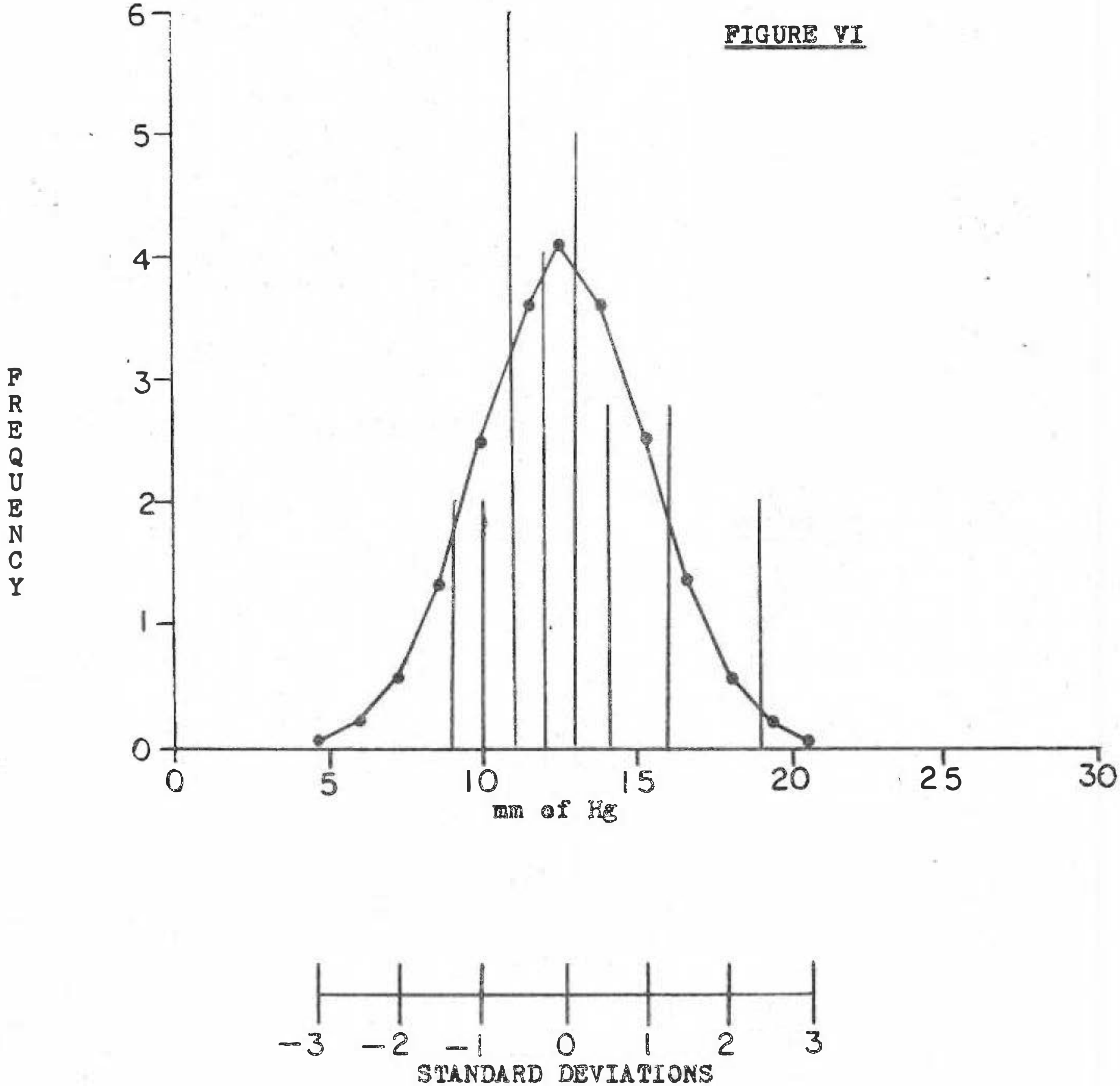
Frequency distribution of readings with the Non-contact tonometer superimposed on the theoretical normal distribution for the population.

FIGURE V



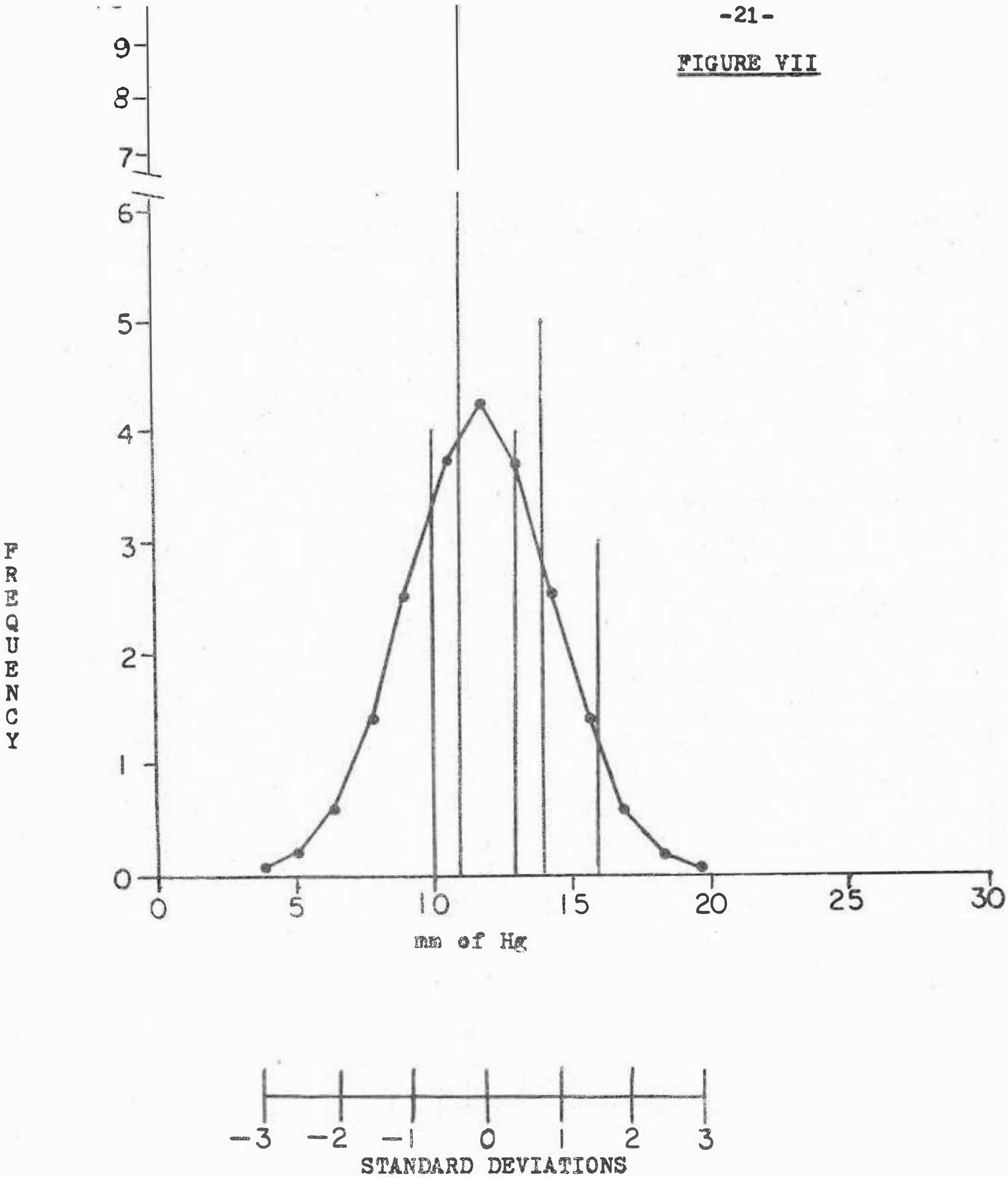
Frequency distribution of readings with the 5.5gr. Schiotz tonometer superimposed on the theoretical normal distribution for the population.

FIGURE VI



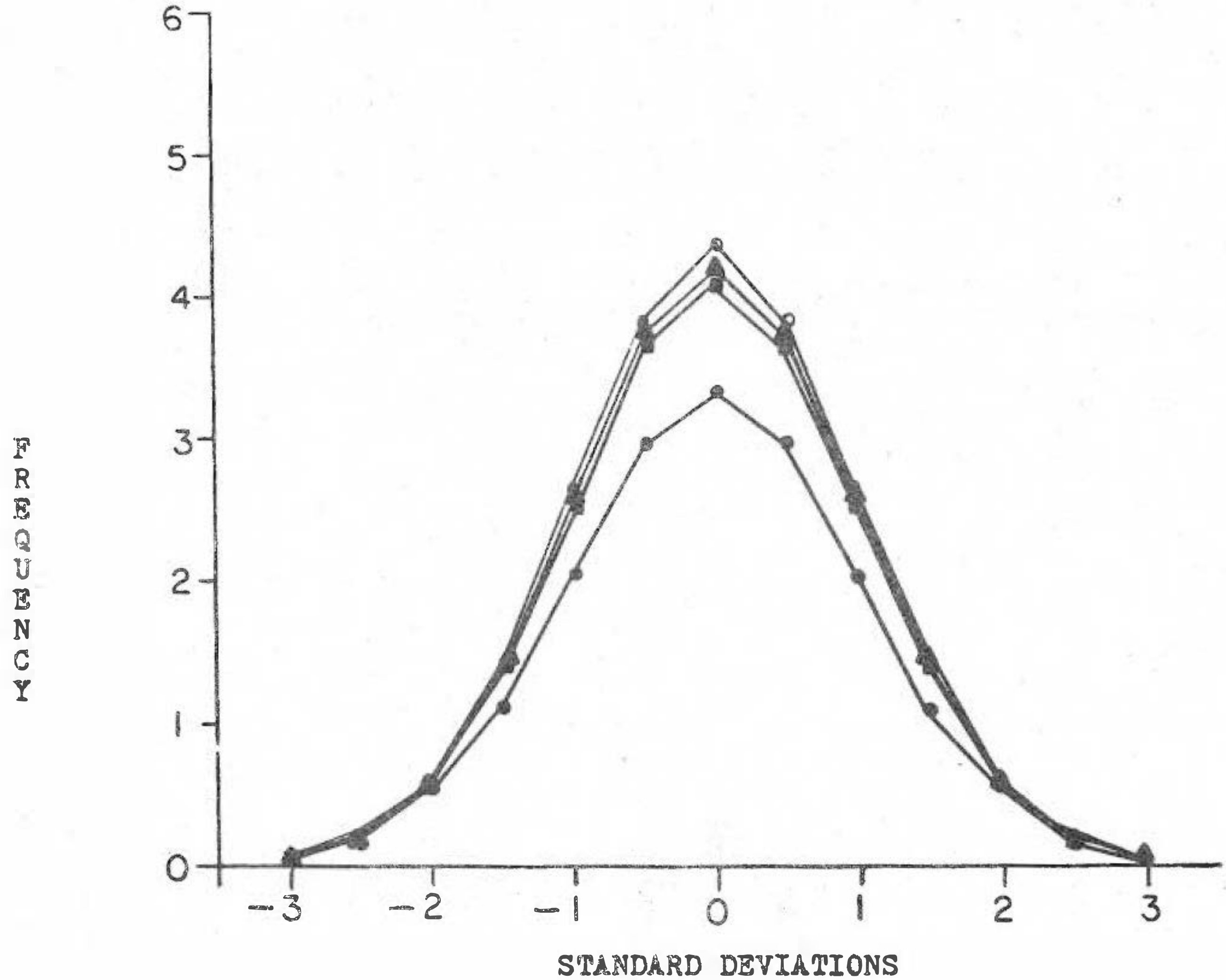
Frequency distribution of readings with the 7.5gr. Schietz tonometer superimposed on the theoretical normal distribution for the population.

FIGURE VII



Frequency distribution of readings with the 10.0gr. Schiøtz tonometer superimposed on the theoretical normal distribution for the population.

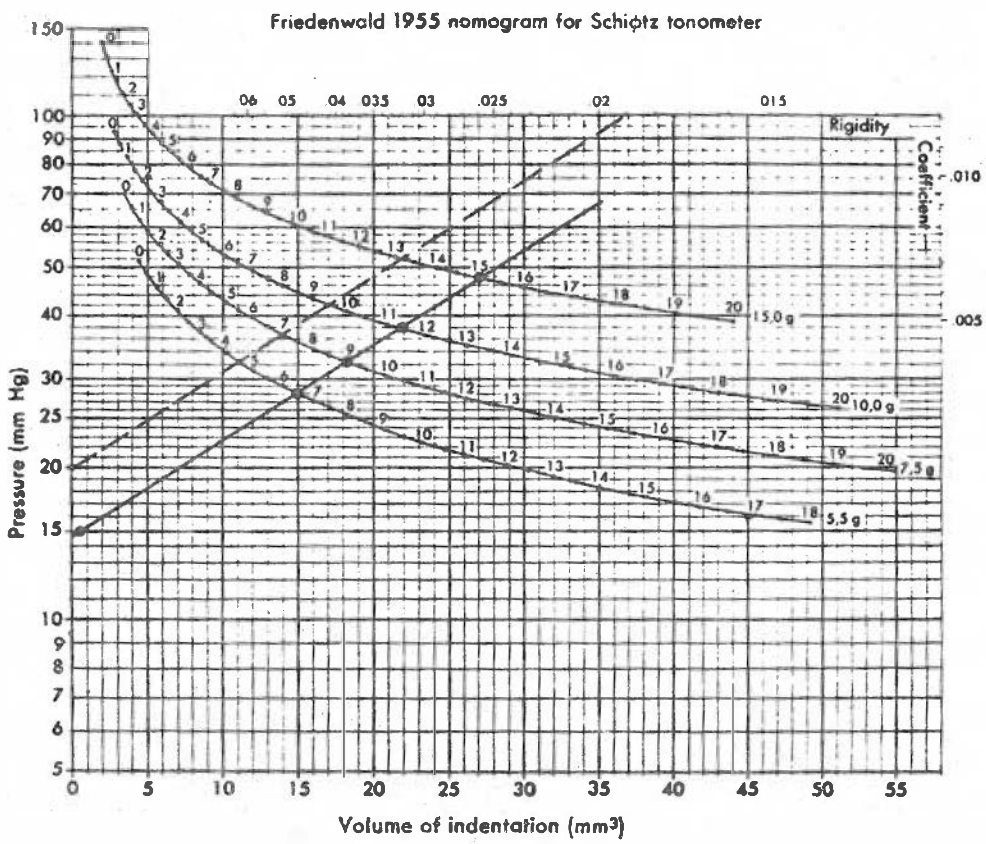
FIGURE VIII



Open circle = Non-contact tonometer distribution
Closed circle = 5.5gr. Schiotz tonometer distribution
Square = 7.5gr. Schiotz tonometer distribution
Triangle = 10.0gr. Schiotz tonometer distribution

Theoretical normal distributions of Non-contact, 5.5gr., 7.5gr., and 10.0gr. Schiotz tonometry values for the experimental population.

FIGURE IX



Friedenwald nomogram taken from Adler's Physiology of the Eye, 1975.

APPENDIX I

Mean Values and Deviation from the Mean

	N.C.T.	5.5gr.Schietz	7.5gr.Schietz	10.0gr.Schietz
Mean Value(mm Hg)	13.57	14.96	12.61	11.79

Deviation from the Mean (mm Hg)

Subject No.	N.C.T.	5.5gr.Schietz	7.5gr.Schietz	10.0gr.Schietz
1	-3.9	2.04	1.39	4.21
2	-1.57	0.04	-1.61	-0.79
3	1.76	2.04	1.39	1.21
4	2.43	4.04	6.39	4.21
5	-0.9	-4.96	-2.61	-0.79
6	6.1	1.04	1.39	2.21
7	-0.9	-1.96	-0.61	-0.79
8	-3.9	6.04	0.39	-0.79
9	-0.57	-1.96	-1.61	-0.79
10	1.76	0.04	-0.61	-0.79
11	-1.9	-4.96	-3.61	-6.79
12	-0.57	1.04	3.39	-0.79
13	1.76	-2.96	-1.61	-1.79
14	-0.57	-2.96	-1.61	-1.79
15	-2.24	2.04	0.39	2.21
16	-2.57	-2.96	-1.61	-0.79
17	-2.43	2.04	0.39	2.21
18	-2.43	6.04	6.39	4.21
19	-2.57	-4.96	-4.61	-1.79
20	6.1	1.04	3.39	2.21
21	0.43	0.04	0.39	1.21
22	-3.24	4.04	0.39	1.21
23	0.9	-1.96	-1.61	-0.79
24	2.43	1.04	-0.61	1.21
25	-1.24	-2.96	-3.61	-6.79
26	-0.57	6.04	3.39	2.21
27	0.76	-2.96	-0.61	-0.79
28	-0.24	-2.96	-2.61	-1.79

APPENDIX II

Value of the ratio: $\frac{\text{Deviation from mean(mm Hg.)}}{\text{Mean(mm Hg.)}}$

Subject No.	N.C.T.	5.5gr.Schiotz	7.5gr.Schiotz	10.0gr.Schiotz
1	-.287	.136	.110	.357
2	-.161	.003	-.128	-.067
3	.130	.136	.110	.103
4	.180	.270	.507	.357
5	-.066	-.332	-.207	-.067
6	.450	.070	.110	.187
7	-.066	-.131	-.048	-.067
8	-.287	.404	.031	-.067
9	-.042	-.131	-.128	-.067
10	.130	.003	-.048	-.067
11	-.140	-.332	-.286	-.576
12	-.042	.070	.269	-.067
13	.130	-.198	-.108	.152
14	-.042	-.198	-.128	.152
15	-.165	.136	.031	.187
16	-.189	-.198	-.128	-.067
17	-.180	.136	.031	.187
18	-.180	.404	.507	.357
19	-.190	-.332	-.366	-.152
20	.450	.070	.269	.187
21	.030	.003	.031	.103
22	-.239	.270	.031	.103
23	-.066	-.131	-.128	-.067
24	.179	.070	-.048	.103
25	-.090	-.198	-.286	-.576
26	-.040	.404	.268	.187
27	.056	-.198	-.048	-.067
28	-.018	-.198	-.207	-.152

APPENDIX III

Value of Rigidity as Determined
by the Equation:

$$\frac{\bar{X}_{NCT} - NCT_n}{\bar{X}_{NCT}} - \frac{\bar{X}_{Schiotz} - Schiotz_n}{\bar{X}_{Schiotz}} = \text{Comparative Rigidity}$$

Subject No.	NCT- 5.5gr.Schiotz	NCT-7.5gr.Schiotz	NCT-10.0gr.Schiotz
1	-.423	-.397	-.644
2	-.119	.012	-.049
3	-.006	.020	.027
4	-.090	-.327	-.177
5	.266	.141	.001
6	.380	.340	.263
7	.065	-.018	.001
8	-.691	-.318	-.220
9	-.089	.086	.025
10	.127	.178	.197
11	.192	.146	.436
12	-.112	-.311	.025
13	.328	.258	-.022
14	.156	.086	-.194
15	-.301	-.196	-.352
16	.009	-.061	-.122
17	-.316	-.211	-.367
18	-.584	-.687	-.537
19	.142	.176	-.038
20	.380	.181	.263
21	.027	-.001	-.073
22	-.509	-.270	-.342
23	.065	.062	.001
24	.109	.227	.076
25	.108	.196	.486
26	-.444	-.308	-.227
27	.254	.104	.123
28	.180	.189	.134

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